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Opportunities of Compressed Biogas Production in Sugar Industry and Distillery

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ABSTRACT

The use of one of the sugarcane industry-based wastes i.e. press mud cake (PMC) is restricted for bio-composting process or directly as fertilizer to improve soil fertility. Fertilizer use is not the best valorization route considering its potential. Increasing consumption of fossil fuels and environmental concern has led to increase use of compressed natural gas (CNG) in the transportation sector. Therefore, biogas is advised as potential fuel to provide continuous supply bio-CNG or compressed biogas (CBG). To decrease the imports of crude oil and natural gas requirement and to increase the economic sustainability of sugar mills, utilization of wastes (PMC in sugar mill and spent wash in distillery) for biogas production through anaerobic digestion (AD) and further purification to produce CBG will definitely generate additional revenue for sugar mills in India. From circular bio-economy perspective, production of value added product such as CBG from PMC and recycle of digestate on organic fertilizer would be essential for sustainability of sugar industry in future. This paper aims to produce a strong outlook on the importance of CBG production through anaerobic digestion and its purification.

Keywords: Bio-gas, CBG, press mud, spent wash.

INTRODUCTION

During the recent few years, sugar mills have tremendously increased their crushing capacities resulting in increase in daily sugar production. This has resulted into decrease in average cane crushing days from 150 days to 100 days. For 200 days, sugar mill machinery and manpower is idle which is resulting in higher overhead and production cost. To overcome this situation, sugar industry must utilize their resources optimally and adopt bio-refinery approach to diversify their product portfolio to bio-fuels such as CBG, green hydrogen, sustainable aviation fuel, bio-chemicals such as lactic acid, gluconic acid, acetic acid and other value-added products.

Spent wash produced during ethanol production is generally treated as waste. Biogas produced from bio-methanation of spent washcan be used for CBG production and bio-methanted spent wash (BMSW) is concentrated to produce powder in dryer. After granulation, BMSW powder can be applied to soil as carbon and potash source. In this way, maximum potential from molasses is extracted by producing environment friendly ethanol and BMSW powder can be recycled back to ecosystem. Similarly, press mud cake can be used to produce CBG and fermented organic manure instead of its use for bio-composting.

India has set a target of increasing the contribution of gas in India's energy mix from existing 6.5% (global average is 23.5%) to 15% by 2030. GoI would like to promote waste / biomass sources like agricultural residue (sugarcane trash), cattle dung, sugarcane press mud cake (PMC), municipal solid waste and sewage

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treatment plant waste, etc. for production of biogas through the process of anaerobic decomposition.

In view of above, bio-refinery approach can be adopted in sugar industry for the production of CBG and fermented organic manure. While developing bio-refinery based product portfolio, products should be evaluated on the basis of their cost economics, raw material availability, usability, greener to environment, their recyclability and policy aspects.

Market potencial and policy support

CBG can be produced from various bio-mass / waste sources including agricultural residue, municipal solid waste, sugarcane press mud, distillery spent wash, cattle dung, sewage and industrial wastes. The estimated CBG potential from various sources in India is nearly 62 MMT with bio-manure generation capacity of 370 MMT.

Government announced mandatory blending of compressed bio-gas in CNG (Transport) and PNG (Domestic) segments of city gas distribution (CGD) Sector on 25th November 2023. CBG blending obligation (CBO) will promote production and consumption of compressed bio-gas (CBG) in the country. The key objectives of the CBO are to stimulate demand for CBG in CGD sector, import substitution for lLiquefied natural gas (LNG), saving in forex, promoting circular economy and to assist in achieving the target of net zero emission etc. It will also encourage investment of around Rs. 37500 crores and facilitate establishment of 750 CBG projects by 2028-29. CBO will be voluntary till FY 2024-2025 and mandatory blending obligation would start from FY 2025-26. CBO shall be kept as 1%, 3% and 4% of total CNG/PNG consumption for FY 2025-26, 2026-27 and 2027-28 respectively. From 2028-29 onwards, CBO will be 5%.

Ministry of New and Renewable Energy, GoI has notified Central Financial Assistance of Rs. 4.0 crore per 4800 kg of CBG per day with maximum assistance of Rs. 10.0 crore per project (as a subsidy) for CBG production. Reserve Bank of India has also included CBG plants under priority sector lending. As per the notification from the Department of Agriculture and Farmers Welfare, GoI, fermented organic digestate coming out from digester of agro-wastes is now approved as fermented organic manure in Fertilizer Control Order (FCO). Subsidy of Rs. 1500 per MT is also announced for fermented organic manure.

CBG off take and distribution

The biogas produced contains approximately 55% to 60% methane, 40% to 45% carbon dioxide and trace amounts of hydrogen sulphide. Biogas is purified to remove carbon dioxide and hydrogen sulphide gases to produce CBG. The CBG can be transported through cylinder cascades or pipelines to retail outlets. There are different models for distribution of CBG from its source to the end consumer. OMCs shall off-take CBG produced from such plants. Oil Marketing Companies (OMCs) shall also provide technical support for such Plants, if required. OMCs propose to procure CBG from existing, upcoming and planned compressed bio gas (CBG) plants in India.

METHODOLOGY

Technologies for biogas production

Biogas is a product from the process of degradation of organic matter by anaerobic bacteria. Bio-methanation process consists of four subsequent chemical and bio-chemical reactions i.e. hydrolysis reaction, acidogenesis reaction, acetogenesis reaction and methanogenesis reaction.

CSTR with adequate arrangement of mixing by providing central and lateral agitators

Continuous stirred tank reactor (CSTR) is applied in industrial-scale biogas plants for treating high-moisture organic waste in recent decades (Mao et al. 2015). Use of CSTR for anaerobic digestion of high solids of lignocellulosic biomass is energy and water intensive and it also requires grinding of the biomass prior to digestion (Nges and Bjornsson 2012).The typical diagram of CSTR is shown in (Figure 1).

Mixed Plug flow reactor with axial mixing

A mixed plug flow reactor system is simple, economical and attractive in terms of efficiency and overall bioconversion compared to CSTR (Gomez et al. 2019). This reactor exploits advantages of plug flow and CSTR type reactor. The typical diagram of mixed plug flow reactor is shown in (Figure 2).

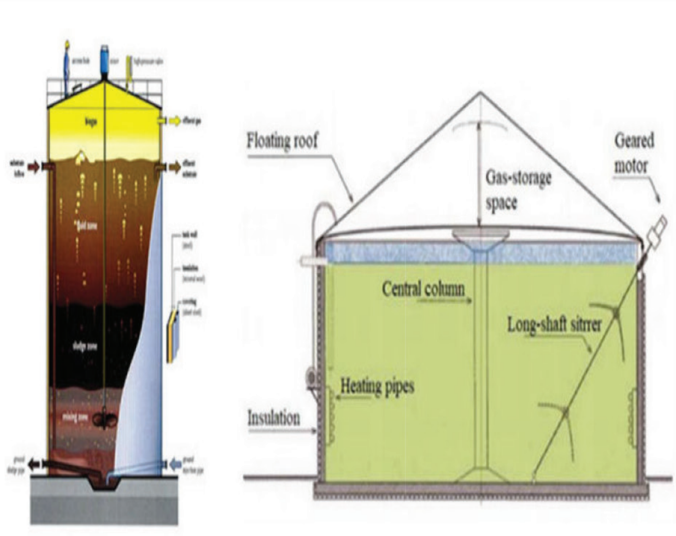

Figure 1 : Typical diagram of CSTR digester with central and lateral agitator arrangements

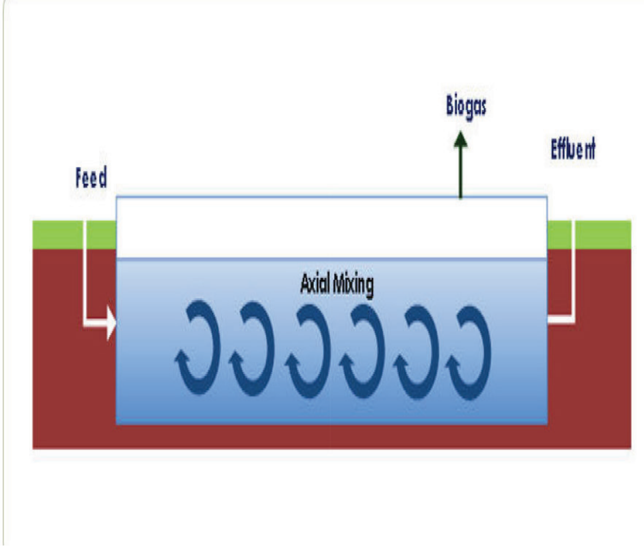

Figure 2 : Typical diagram of mixed plug flow reactor with axial mixing

Dry fermentation

Solid-state anaerobic fermentation (SSAF) is another process of fermentation which is operated with higher solid loading or OLR. Screw conveyors are used for feeding or removing digestate from digester. Digestate from digester is separated into two streams by decanter i.e. liquid stream and solid stream.

- *Liquid stream:* 70-80 % of liquid stream can be recycled back for feed preparation. The remaining 20 % of liquid stream will be sold as bio-fertilizer (Rs 0.2 per lit).
- *Solid stream (Fermented Organic Manure):* It contains 50-60 % moisture which can be further sun dried to 30 % moisture. After drying, solids will be pulverized and screened and packed in bag and sold as fermented organic fertilizer (Rs. 2500- 3000/ton).

Biogas purification

The biogas generated from the anaerobic digesters has methane around 55-60 % and 30-35 % carbon dioxide and other impurities such as hydrogen sulfide. The biogas has to be purified to remove hydrogen sulfide (H_2S), carbon dioxide (CO_2), water vapor and compressed as Compressed Bio Gas (CBG), which has methane (CH_4) content of more than 90% (Nallamothu et al. 2013). There are different technologies already in the market for the purification biogas to be considered as CBG which are enlisted below.

Hydrogen sulfide (H_2S) removal

The main issues due to the high concentrations of H_2S in biogas are its corrosive action, which damages engines and the production of sulfur oxides (SOx) due to H_2S combustion. Hence, the bio-gas needs to be purified to remove H_2S. For removal of H_2S, various technologies available are enlisted in (Table 2).

Biological fixation

In biological fixation, micro-organisms such as sulphur oxidizing bacteria oxidizes H_2S to S, SO_4^{-2}, and H_2SO_4 as the final product depending on the operational conditions (aerobic, anaerobic and anoxic conditions). Different electron acceptors such as O_2 (aerobic), NO_3^- and NO_2^- (anoxic) are used for H2S oxidation by the micro-organisms (Basu et al. 1996).

Iron chloride dosing

Iron in the form Fe (III) such as FeCl3 has the capability to oxidise hydrogen sulphide present in biogas. Fe (III) reduces itself to ferrous ion (Fe (II)) and forms an insoluble precipitate.

Table 2 : Comparative evaluation of technologies to remove H_2S from biogas

Method	Efficiency	Capital cost	Operation & maintenance	Complexity
Biological fixation	Moderate	Moderate	Low	Moderate
Iron chloride dosing	Moderate	Low	Moderate	Moderate
Water scrubbing	High	High	Moderate	High
ISET (IISc)	High	Moderate	Moderate	Moderate

Water scrubbing

Therefore, water can be used as an adsorbent for H2S removal from biogas. In this method, biogas is passed into the bottom of a column which is filled with water through a diffuser. A diffuser spreads the biogas into fine bubbles and therefore the residence time and overall mass transfer area is increased which increases the removal of H2S from water. The biogas collected at top of the column is enriched with methane.

ISET

For H_2S removal, Indian Institute of Science has developed Sulfur Extraction Technology (ISET). ISET process developed by IISc is based on the redox reaction of chelated polyvalent metal ion. In this particular process, iron in aqueous medium, which exists in both Fe^{3+} and Fe^{2+} form, is used for scrubbing hydrogen sulfide from the biogas. The sulfur present in the hydrogen sulfide is precipitated as elemental sulfur. The H_2S in biogas is reduced from 300 ppm to below 10 ppm using ISET process.

CO_2 removal

Presence of carbon-dioxide in the bio-gas reduces its calorific value. For removal of carbon dioxide, various technologies available are enlisted below.

Pressure Swing Adsorption (PSA)

In this technique, carbon dioxide is separated from the biogas by adsorption on a surface under elevated pressure and also desorb the undesired gas components. The adsorbing material, usually activated carbon or zeolites, is regenerated by a sequential decrease in pressure before the column is reloaded again. Also, the use of double PSA units seems to be an effective and feasible for biogas upgrading process to get complete separation of biogas components.

Water Scrubbing

Due to higher solubility in water carbon dioxide dissolved to a higher extent than methane, particularly at lower temperatures. In the scrubber column, carbon dioxide is dissolved in the water, while the methane concentration in the gas phase increases. The gas leaving the scrubber has therefore an increased concentration of methane. The operation of water scrubbing system is highly dependent on particular temperature and pressure in water to form dilute carbonic acid. In this process of purification, from the bottom of the scrubber, raw biogas is fed to a packed bed adsorption column and from the top, pressurized water is sprayed.

Chemical scrubbing - Monoethylammine (MEA) system

This system achieve 99.9% purity with negligible loss of methane. Mono-ethanol-amine (MEA), di-ethanol-amine (DEA) and methyldiethanolamine (MDEA) are the most commonly used amines in scrubbing applications. The CO_2 absorbing capacity of amines is easily degraded by the presence of SO_2, NO_2, HCl, HF, or O_2 in the gas stream which usually forms irreversible byproducts that reduce the reaction rate during the absorption process.

Membranes

Dry membranes are made of materials that are permeable to carbon dioxide and water and non-permeable to methane or permeable to methane to a very low extent are used. The membranes should be resistant to the impurities present in biogas, robust against fouling and should withstand high pressures (20–25 bars). The best gas separation properties are observed in non-polymeric membranes (alumina and zeolites). However, high manufacturing costs and inadequate mechanical properties are some of the disadvantages of these membranes.

For removal of carbon dioxide, comparative parameters of various technologies available are enlisted in (Table 4).

Compression and storage

Upgraded or purified biogas will be compressed to 250 bars for compressed biogas production (CBG).

Table 4 : Comparative evaluation of technologies to remove CO_2 from biogas

Parameter	Pressure Swing Adsorption (PSA)	Water scrubbing	Amine scrubbing	Membrane
Methane content in upgraded gas (%)	up to 99	up to 98	up to 99	up to 99
Output pressure (bar)	4	6	1	16
Electricity consumption (kWH/m^3)	0.25	0.25	0.15	0.22
Methane loss (%)	1-3	1.0	0.1-0.2	0.3-0.5
Chemical usage	Adsorbents	Water	Toxic	No
Ease of operation	Medium	Medium	Complex	Easy
Maintenance	High	High	Medium	Low
Footprint	Medium	Medium	Large	Low

Compressing the biogas reduces the storage requirements and concentrates energy content (Kapdi et al. 2005). The compression can be performed in two to three stages. After compression, CBG is supplied through cascadesto the oil company retail outlets.

RESULTS AND DISCUSSION

Sugar industry perspectives

There are about 540 Sugar mills and 386 distilleries in India. The estimated CBG potential from sugar industry is about 2 million metric ton (potential to reduce natural gas import by 5 %). CBG projects can be easily integrated with existing sugar mill operations. For example, the gas produced can be used to power vehicles used to transport sugarcane or to operate other equipment in the factory such DG set. This can help to reduce the fuel expenses and carbon footprint of sugar mills. The gas can also be sold to oil companies or directly to consumers through the sugar mill's own pump. This can help to create a market for CBG and increase the profitability of sugar mills.

CBG projects have a payback period around 3 years (Table 5) in case of press mud cake and 2 years in case of spentwash (Table 6). CBG projects will generate additional income for sugar mills through the sale of gas and fermented organic manure. This makes them a viable investment for sugar mills, especially considering the long-term benefits of CBG production.

The solid waste produced from CBG projects, known as fermented organic manure, is eligible for a subsidy of Rs. 1.50 per kg under the Fertiliser Control Order (FCO). Fermented manure is a high-quality organic fertilizer that can improve soil fertility and crop yield. This can help to offset the cost of operating the project and provide an additional source of income for sugar mills.

CBG plant of 5-10 TPD will be suitable for sugar mill having capacity from 5000 TCD to 10000 TCD on PMC basis. 100 KLPD distillery operating using bio-methanation-evaporation-dryer route can go for 10-15 TPD CBG plant (spentwash and PMC feedstock-separate digester with common biogas purification). Power cost is the mostly critical factor in CBG production as grid power will be costly. Power for 300 days from distillery boiler-TG can resolve this issue. Other feedstock such as co-feeding of poultry waste, dairy, municipal solid wastes and plant nearness to industrial area will be an added advantage. Plant nearness to OMC’s CNG pumps will be also an added advantage. On the other hand, sugar mills can set-up their own CBG pumps and CBG can be sold to vehicles (Diesel to CBG conversion kit) coming to sugar mill.

Major challenges

India lacks the established infrastructure to transport and distribute CBG to end-users, making it difficult

Table 5 : CBG plant 5 ton per day on press mud cake

Sr. No.	Particulars	Values
1.	**CBG Plant Capacity (MT /day)**	**5.0**
	CBG production (Kg/day)	5000
	Biogas yield (M^3/MT of PMC)	100
	Raw Biogas production (M^3/day)	12500
	Press Mud Plant Capacity (MT /day)	125
	Fermented Organic fertilizer (MT/day)	20
	Total operating days	300
	Total PMC required per annum (MT)	37500
2.	**Capital investment (Rs. lakhs)**	**1700**
	Total Capital investment after availing CFA (Rs. lakhs)	**1300**
3.	**Income**	
	Selling price (Rs. per kg of CBG)	65.0
	Selling price (Rs. per kg of fermented organic fertilizer)	1.0
	CBG (Rs. lakhs per annum)	975.0
	Fermented Organic fertilizer (Rs. lakhs per annum)	60.0
	Total income per annum (Rs. lakhs per annum)	**1035.0**
4.	**Expenses (chemical, electricity, manpower, etc) + raw material**	
	Operating cost (Rs. per kg of CBG) (electricity ,chemical, Manpower, etc.)	30
	Cost (Rs lakh per annum)	450.00
	Press mud rate (Rs. per MT)	500.0
	Press mud cost Rs. lakh per annum	187.5
	Total cost (Rs. lakhs per annum)	**637.5**
	Total cost (Rs per kg of CBG)	**42.5**
5.	**Total profit per annum (Rs. lakhs)**	**397.5**
6.	**Payback period (year)**	**3.3**

Table 6 : CBG plant 5 ton per day on spent wash

Sr. No.	Particulars	Values
1.	**CBG Plant Capacity (MT /day)**	**5.0**
	Raw Biogas production (M^3/day)	12500
	Total operating days	300
2.	**Capital investment (Rs. lakhs)**	**1200**
	Total Capital investment after availing CFA (Rs. lakhs)	**900**
3.	**Income**	
	Selling price (Rs. per kg of CBG)	65.0
	CBG (Rs. lakhs per annum)	975.0
	Total income per annum (Rs. lakhs per annum)	**975.0**

4.	**Expenses (chemical, electricity, manpower, etc)**	
	Operating cost (Rs per kg of CBG) (electricity ,chemical, Manpower,etc)	30
	Cost (Rs lakh per annum)	450.0
	Total cost (Rs. lakhs per annum)	**450.0**
5.	**Total profit per annum (Rs. lakhs)**	**525.0**
6.	**Payback period (year)**	**1.7**

to expand its use as a transportation fuel or as a substitute for natural gas. India needs to work on improving infrastructure, increasing awareness, and addressing the distribution infrastructure. During the PMC storage, there will be natural composting of it. Biogas potential of PMC will go down over storage of it. This challenge need to be addressed in future. It should be noted that sugar mills should not rely solely on press mud and spent wash to feed their CBG plants. They should also use alternative feeds, such as sugarcane bagasse, bagasse pith and Napier grass, to ensure a steady supply of gas throughout the year.

CONCLUSION

Considering SATAT program initiatives, CBG production from PMC and spentwash seems to be next golden opportunity for sugar industry and distillery to diversify in renewable bio-fuel. Production of CBG and recycle of digestate as fertilizer looks to be golden opportunity for sugar industry in future.

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